H.A. FADLY, E. SUROJO, N. MUHAYAT, TRIYONO
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EFFECT OF FLAME STRAIGHTENING TREATMENT ON THE MICROSTRUCTURE OF FILLET WELD S355J2+N STEEL

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Flame straightening is the most common method applied in welded steel to mitigate distortion. This research showed that flame straightening can be safely applied on fillet T-joint S355J2+N steel. The microstructure and hardness on the back surface of the fillet T-joint were affected by the flame straightening process. The surface experienced a decrease in hardness and changes in the shape and size of the microstructure. In this research, the welding procedure standard (WPS) was applied to the welding test coupon. The straightening process was then applied on the back surface of the fillet T-joint by heating and then cooling rapidly with an air jet. Lastly, microstructure investigation and hardness test were performed on the flame-straightened area.

Keywords: S355J2+N, fillet weld, flame straightening, microstructure, hardness

INTRODUCTION

Welding is the most commonly used joining process in component manufacturing and assembly due to its good reliability and high production speed. Another advantage is the cost-effectiveness compared to other manufacturing processes. Meanwhile, Gas Metal Arc Welding (GMAW) is one of the most commonly used welding methods in the manufacturing industry because of its advantages, such as the ability to weld all positions and good quality [1,2]. This method is used in railway construction. An example of metal welding in this industry is the S355J2+N fillet weld material, which is applied to the lower part of the main frame structure called the underframe.

This high-strength, low-alloy steel material supports the overall load of the train, and therefore a strong material is required. Subsequently, each part of the subframe is connected using a welding process, and a large number of welding processes generate excessive heat, which causes problems in the structure. The problem is that the heat distribution on the material that is being welded is unpredictable. The distortion of the welded structure can result in a visual appearance and the risk of being out of tolerance, and to solve this problem, flame straightening is used [3]. By using an oxy-acetylene burner, heat is transferred at a specific temperature to the structure forming a specific pattern, and allowing the dimensions and shape to meet the agreed tolerance standards [4].

The effect of flame straightening on the material has been examined [4–6], but research on the effect of flame straightening on the area closest to the material welding line S355J2+N is still limited. Therefore, this research investigated the effect of flame straightening on the microstructure and metal hardness on the back surface of the weld. The splicing of the metal T-joint was accomplished using the GMAW process, then the back surface is flame-straightened parallel to the material connection.

Triyono (e-mail: triyono74@staff.uns.ac.id), H.A. Fadly, E. Surojo, N. Muhayat, Mechanical Engineering Department, Universitas Sebelas Maret, Surakarta, Indonesia

EXPERIMENTAL PROCEDURES

The material used was two S355J2+N plates with dimensions of 500 x 150 x 12 mm and 500 x 50 x 10 mm paired with a symmetrical T-joint shape as shown in Figure 1. The welding wire used was AWS ER 70S-6 type, and the material composition is shown in Table 1. The two plates were joined with GMAW by a qualified operator using a certified and approved welding procedure with welding parameters and welding process detail as listed in Table 2 and Table 3 respectively.

After welding process, the non destructive test (NDT) process was performed with a magnetic particle test before

Table 1 **Chemical composition of materials /wt.%**

Element	Materials	
	S355J2+N	ER70S-6
P	0,014	0,017
C	0,1676	0,07
S	0,0026	0,012
Mn	1,397	1,47
Cu	0,016	0,11
Si	0,202	0,9
Cr	-	0,2
Mo	-	0,004
Ni	-	0,003
V	-	0,003
Fe	Bal.	Bal.

proceeding to the next step. Flame straightening was applied along the back surface. The natural flame of oxy-acetylene gas was fired back and forth under the guidance of the Linde Group [7] Then, it reached temperatures of 600 °C and 800 °C. The procedure is presented in Figure 2, where the travel speed of the burner was kept constant at 30 cm/minute. After reaching the specified temperature, the material was cooled using sprayed water. Specimens were prepared by cutting the material crosswise and then testing for hardness at a depth of 1 mm, 2 mm, and 3 mm to determine the difference between flame straightening at 600 °C and 800 °C.

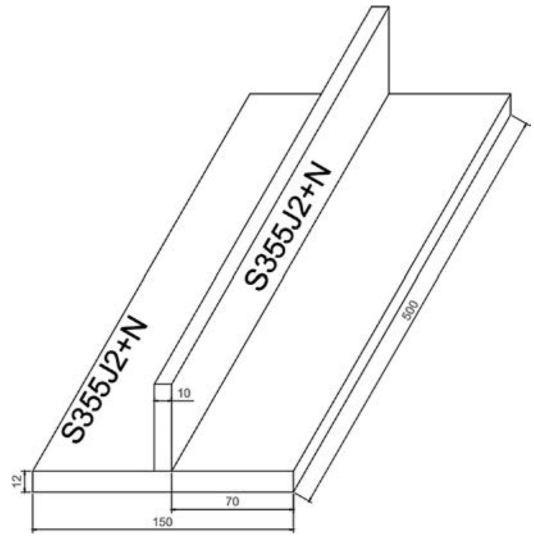

Figure 1 Weld joint configuration.

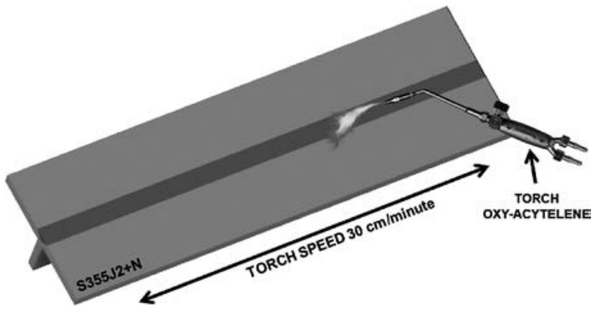

Figure 2 Flame straightening process.

Table 2 **Welding parameters**

Welding Process	Semiautomatic (GMAW) (135)
Type of weld	Fillet weld
Pass	Multi-pass
Size of weld	Max. 50
Position	Flat
Type of material	S355J2+N
Thickness of material	12-50 mm
Filler metal	AWS ER 70S-6 (A5.18)
Diameter of filler	1,2 mm
Shielding gas	Ar 82 % + CO_2 18 %
Shielding gas flow	15-17 l/min
Metal transfer mode	Spray
Cleaning method	Grinding, Brushing

Table 3 **Welding process detail**

Passes	1st (Root Pass)	2-N pass
Polarity	DC+	DC+
Ampere/A	225-240	240-270
Voltage/V	22-24	24-27
Wire speed /mm/min	30-50	100-120
Travel speed /mm/min	250-300	270-390
Heat input /J/mm	1.762	1.536

RESULTS AND DISCUSSION

Observations were made under a microscope at various points of the diameter of the sample to determine the structure formed. Figure 3 shows the microstructure of the base metal material S355J2+N. The microstructure formed showed a combination of ferrite (light) and pearlite (dark). This material experienced a rolling process in its formation, and therefore pearlite generally formed elongated towards the rolling process [8, 9].

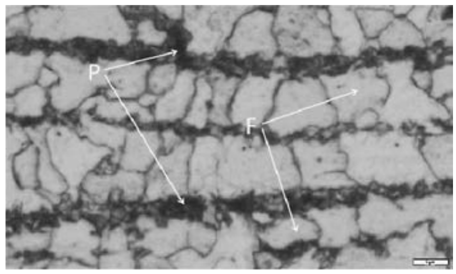

Figure 3 Microstructure of S355J2+N base metal.

The pearlite formed in the microstructure was estimated to be 20 %. The ferrite phase was the most dominant phase, and therefore forms the main characteristics of S355J2+N [8]. In the flame straightening, the temperature variations used were 600 °C and 800 °C. At 600 °C in a relatively short time, a phase transformation is almost impossible, since this temperature is still be-

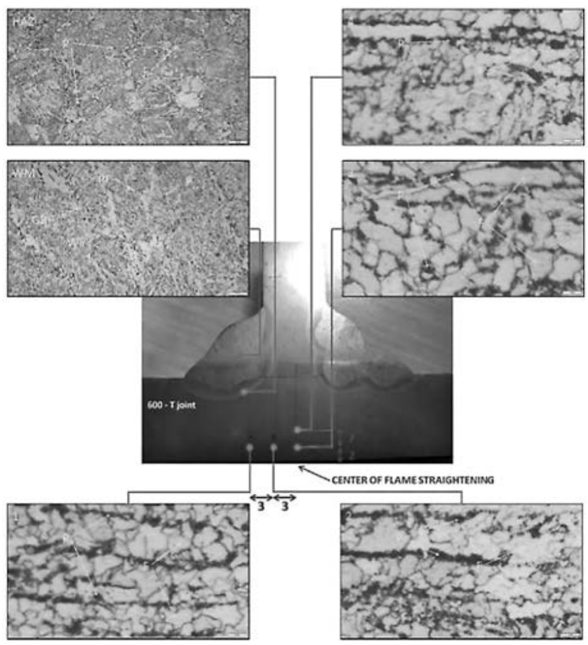

Figure 4 Microstructure of 600 °C flames straightened T-joint.

low the recrystallization temperature. Figure 4 shows the shape changes in the microstructure. At the center of the flame straightening, the initially longitudinally distributed perlite structure has dissolved. This change did not occur in a large area where at a distance of 3 mm from the center of the flame straightening, only part of the structure was transformed into pearlite, columnar and equiaxed forms. This also proves that the effect of heat from fillet welds did not reach this area. At a distance of 6 mm to the side from the center of the flame straightening, the microstructure formed is similar to the base metal microstructure as shown in Figure 3, where the pearlite formed is columnar following the direction of the rolling process.

In Figure 5, the phases formed in the microstructure are pearlite and ferrite. Other phases are not visible in the microstructure because the heating process is relatively short and does not have a significant impact on the formation of other phases such as martensite or bainite. The area affected by the flame straightening process is also relatively the same, with the most affected area being the center of the heating area. The shape of the pearlite in the center of the heating area has changed from columnar to equiaxed. The heating applied to the material provides sufficient energy for the structure to undergo dislocation rearrangement and subgrain formation [4, 5,10].

The ferrite formed in the microstructure has a very dominant polygonal shape and differs only in grain size between the two temperature variations. This polygonal ferrite appears due to the release of carbon in the grain boundary area quickly, therefore, it causes the grain to have many angles. Polygonal ferrite is different from acicular ferrite which tends to be more ductile than acicular ferrite which has the property of increasing strength [11,12]. In Figures 4 and 5, it can be seen that the size of the polygonal ferrite tends to increase in proportion to the temperature difference between the two.

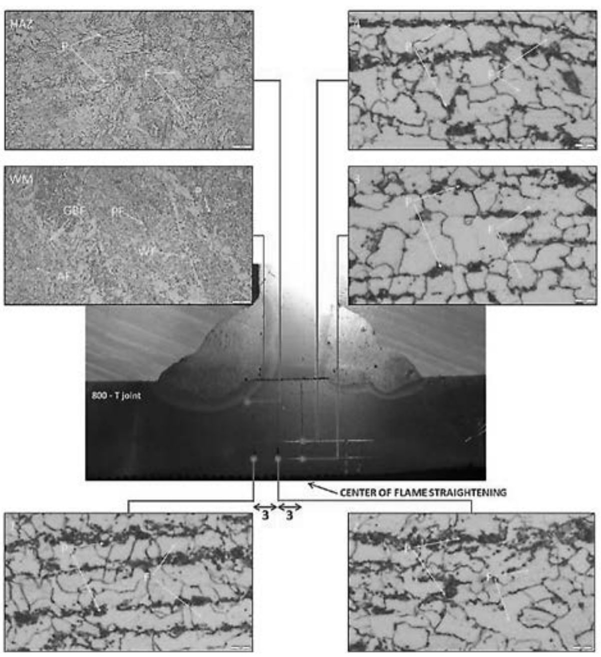

Figure 5 Microstructure of 800 °C flames straightened T-joint.

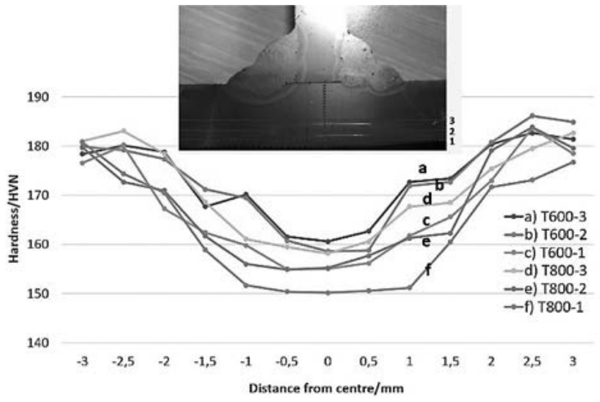

Figure 6 Hardness distribution of 600 °C and 800 °C flames straightening.

The dominant polygonal ferrite in the structure gives the structure more flexible properties. This can be seen in Figure 6, which shows the results of the hardness test performed at a specific depth with a distance of 1 mm. Based on the results of the hardness test, the part with the greatest change was at a heating temperature of 800 °C. The decrease in hardness experienced by the material occurs about 16% at a depth of 1 mm from the center of the flame straightening. The results of this decreasing hardness test will gradually decrease with a certain depth. This shows that only the area affected by the penetration of the flame straightening process will be affected by the material strength.

Flame straightening at a temperature of 600 °C has a relatively smaller decrease with a hardness decrease of about 11 % at a depth of 1 mm from the center. The phenomenon of decreasing hardness is a correlation of the change in the structure shape from columnar to equiaxed. According to Lacalle et al. [10], the flame straightening process experienced by the material is in the form of intercritical annealing in which the pearlite is partially dissolved due to the heating and cooling processes in a relatively short time, causing the pearlite to lose its columnar shape, therefore, it causes the material to decrease in strength although not too significantly.

CONCLUSIONS

Based on the research carried out, the following conclusions are obtained:

- Changes in the microstructure and hardness of the centerline back surface of fillet welding are only affected by the flame straightening process, and the effect of heat from welding has no effect due to the material thickness.
- The material experiences a decrease in hardness and changes in the shape and size of the microstructure.

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Note: The responsible English translator is the Native Proofreading Service - in Indonesia.